ANSWERS: Bond Enthalpy calculations

1)

Bonds broken:	**Bonds formed**:
C–H × 1 Cl–Cl × 1	C–Cl × 1 H–Cl × 1
414 + 242 = 656	324 + 431= –755

656 kJ + (–755 kJ) = –99.0 kJ mol^{-1}

OR

Bonds broken:	**Bonds formed**:
C–H × 4 Cl–Cl × 1	C–Cl × 1 C–H x 3 H–Cl × 1
1656+ 242 = 1898	324 + 1242+ 431= 1997

1898 kJ + (–1997 kJ) = –99.0 kJ mol^{-1}

2) Enthalpy change = Σ(bonds broken) – Σ(bonds formed)

$x = E_{(C=O)}$

Bonds broken = 7(C–H) + 2(C–C) + 1(C–O) + 1(O–H) + 4.5(O=O)
= 7(414) + 2(346) + 358 + 463 + 4.5(498)
= 2898 + 692 + 358 + 463 + 2241

Bonds broken = 6 652 kJ mol^{-1}

Bonds formed = 6(C=O) + 8(O–H)
= 6(x) + 8(463)
= 6(x) + 3704

–2010 = (6652) – (6(x) + 3704)
–2010 = 2948 – 6 (x)
–4958 = – 6(x)

$E_{(C=O)}$ = **826 kJ mol^{-1}** OR **826.3 kJ mol^{-1}**

3) Enthalpy change = ∑bonds broken – ∑bonds formed

Bonds broken	Bonds formed
C − H 413 × 6 = 2478	C=O 745 × 4 = 2980
C − O 358 × 2 = 716	O−H 463 × 8 = 3704
O − H 463 × 2 = 926	
O = O 498 × 3 = 1494	
+5614	− 6684

$\Delta_r H = -1070$ kJ mol^{-1}

OR

Bonds broken = 4688   Bonds formed = 5758

4) Enthalpy change = bonds broken – bonds formed

$x = E_{(O–H)}$

Bonds broken = 5(C–H) + 1(C–C) + 1(C–O) + 1(O–H) + 3(O=O)
= 5(412) + 348 + 360 + x + 3(496)

Bonds broken = 4256 + x *(4256)*

Bonds formed = 4(C=O) + 6(O–H)
= 4(743) + 6(x)
= 2972 + 6(x) *(2972 + 5x)*

–1379 = (4256 + x) – (2972 + 6(x))
–1379 = 1284 – 5 (x)
–2663 = – 5(x)

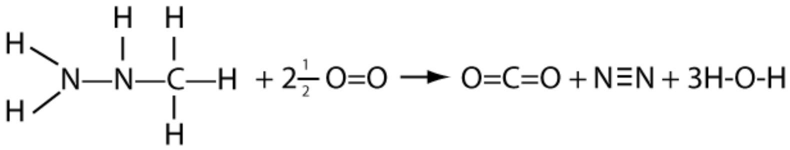
x (O–H) = **533 kJ mol^{-1}** OR **532.6 kJ mol^{-1}**

5) Sum of bond energies broken – sum of bond energies formed

= (339 + 391) – (431 + 286)
= 730 – 717
= 13 kJ mol^{-1}

OR (breaking and forming all bonds)
= (1242 + 339 + 1173) – (1242 + 286 + 782 + 431)
= 2754 – 2741
= 13 kJ mol^{-1}

6) (i) The energy required to break a bond
(ii)



$\Delta_c H^O = \Sigma E_B(\text{reactants}) - \Sigma E_B(\text{products})$

$= 3E_B(\text{N–H}) + E_B(\text{N–N}) + E_B(\text{N–C}) + 3E_B(\text{C–H}) + 2.5\ E_B(\text{O=O})$
$- 2E_B(\text{C=O}) - E_B(\text{N≡N}) - 6E_B(\text{O–H})$

$= 3\times391 + 163 + 286 + 3\times414 + 2.5\times498$
$-2\times804 - 941 - 6\times463$

$= -1218$ kJ mol^{-1} (or heat released = 1218 kJ / kJ mol^{-1})

Bonds broken			**Bonds formed**					
3N–H	391 × 3	= 1173	2C=O	804 × 2	= 1608	N–N	163	= 163
N ≡ N	941	= 941						
C–N	286	= 286	6O–H	463 × 6	= 2778			
3C–H	414 × 3	= 1242						
2½ O=O	498 × 2½	= 1245						
Adds to		= 4109	Adds to		= 5327			

7) $H_2(g) + \frac{1}{2} O_2(g) \rightarrow H_2O(s)$
H–H + ½ O=O → 2 × H–O
$\Delta_r H = 436 + \frac{1}{2}(498) - 2(463)$
$\Delta_r H = -241$ kJ mol^{-1}

$\Delta_{vap} H°(H_2O) = \Delta_f H°(H_2O, g) - \Delta_f H°(H_2O, \ell) = -241 - (-286) = 45$ kJ mol^{-1}

$M(H_2O) = 18$ g mol^{-1}
Heat required to vaporise 100 g water = 45/18 × 100 = 250 kJ

8) i) $\Delta_r H = \Sigma E_{\text{bonds broken}} - \Sigma E_{\text{bonds made}}$
$-41.2 = E_{CO} + (2 \times 463) - (2 \times 743) - 436$
$E_{CO} = -41.2 - 926 + 436 + 1486$
$= 954.8$ or 955 kJ mol^{-1}
Accept answer with 3 significant figures.
OR a valid process which uses bond energies to obtain correct answer
Eg $\Delta_r H = \Sigma E_{\text{bonds broken}}$ (positive values)
$+ \Sigma E_{\text{bonds formed}}$ (negative values)

ii) Bond breaking **:** absorbs energy / endothermic.

iii) The double bond is stronger than the single bond as it involves the sharing of two electron pairs rather than one as occurs in the single C–O bond. More (less) energy : required to break : double (single) bonds.

9) a) $\Delta_r H = \Sigma E_{bonds\ broken} - \Sigma E_{bonds\ made}$
$= (2 \cdot 436 + 498) - (4 \cdot 460) = +1370 - 1840$
$= -470$ kJ mol

b) $H_2O(l) \longrightarrow H_2O(g)$

c) Energy must be absorbed to break the attractions (hydrogen bonds) holding the molecules together in the liquid state.

d) $2H_2O(!) \longrightarrow 2H_2(g) + O_2(g)$ $\Delta_r H = +572$ kJ
$2H_2(g) + O_2(g) \longrightarrow 2H_2O(g)$ $\Delta_r H = -470$ kJ
$2H_2O(!) \longrightarrow 2H_2O(g)$ $\Delta_r H = +102$ kJ
$H_2O(!) \longrightarrow H_2O(g)$ $\Delta_r H = +51$ kJ
$\Delta_{vap}H_o(H_2O) = +51.0$ kJ mol_{-1}